IMMAGE: Internet-based Modeling, Mapping, and Analysis for the Greater Everglades: Project Description

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Statement of Problem

Recent analyses using current IPCC projections of sea level rise and LIDAR data for the eastern portions of Miami-Dade County suggest that coastal areas in South Florida will be subjected to the degradation of coastal habitats, contamination of municipal water supplies by the intrusion of salt water into coastal aquifers, alteration of groundwater flow patterns, and increased risk of surge-related flooding and wind damage from coastal storms (Deyle and others, 2007; Renken, 2005). It is critical that water planners, as well as park managers and municipal authorities have the best tools to assess the societal risks and economic impacts that these adverse environmental changes could have on nearby communities, protected lands, and the region as a whole.

Development and water management policies being debated today in South Florida will commit public and private capital to infrastructure and facilities with design lives that reach well into the period of time when the impacts of sea level rise are expected to be felt. Surface-water control canals, municipal water distribution networks, and wastewater and storm water collection systems have design lives on the order of 30 to 75 years. Sewage treatment and wastewater reclamation facilities have design lives close to 50 years. The anticipated rise in sea level during the next century may compromise the functioning of these engineered systems and may stress the ability of associated natural systems to adapt.

In evaluating and preparing for possible outcomes, alternative climate and land use scenarios are needed to evaluate the impacts of sea level rise and severe storms on existing and future land portfolios and social infrastructure. Analysis of the scenarios need to incorporate both physical and socioeconomic constraints to assess the natural / human tradeoffs of land use so that planning decisions about mitigation and adaptation make sense in planning for future climate changes. It is also critical that these scenarios be based upon the best-available monitoring data and numerical flow models, rather than relying solely on static simulations of sea level rise using elevation data.

An impressive body of work has been done in the last several years on numerical models to forecast the impact of sea level rise on salt water intrusion, inland flooding, surge from coastal storms, and the resulting impact on the suitability of habitat for key species in the Greater Everglades. These models are among our most powerful tools in forecasting future trends and evaluating alternative restoration and preservation policies. Unfortunately, the full potential of these models has not yet been realized. The output of a typical model run is usually a static data table or a derived graphic. If a user wants to evaluate how changing the input parameters affects the results, the model needs to be run again using the new parameters. Since many models take hours or even days to run, evaluating a large number of parameter sets can be a time consuming and tedious process.

Approach

The IMMAGE project will address this need by developing a framework of online GIS-based interfaces to four selected models, thereby enhancing their usability and making them available to a broader user community. The approach is relatively simple: by running models multiple times in advance using the maximum likely range of input parameters, all the necessary model output can be then stored in a server database (Fig. 1). Web applications can then be developed to allow users to select the desired input parameters, retrieve the necessary model output from the database, and display the output in a map viewer with other relevant data - all online. Without the need to run the models online, this process is relatively fast, allowing the user to run multiple scenarios in a short period of time, then generate paper or soft copy tables and/or graphics of the results.

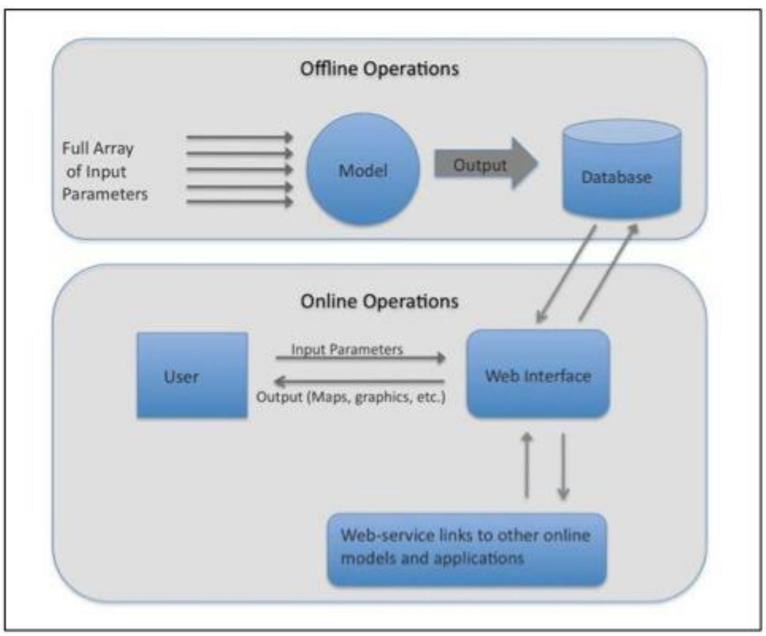

Figure 1 – Generalized schematic of IMMAGE web-based model interface

Through web services, the interface to each model will also be capable of both serving model output to other web-based models and applications, as well as consuming web services to acquire additional data not available in the framework database.

Over the proposed 3-year lifetime of this project, Web interfaces will be developed for the following four models:

1) The BIscayne SouthEastern Coastal Transport (BISECT) model, a coupled ground and surface water model developed by Eric Swain and others at USGS's Florida Water Science Center

2) Habitat distribution models that utilize output from BISECT, developed by Leonard Pearlstine and others at the Everglades National Park

3) The Sea, Lake and Overland Surges from Hurricanes (SLOSH) model developed by NOAA's National Hurricane Center

4) FEMA's HAZUS-MH multi-hazard loss analysis program

Study Area

The area to be covered by this project includes the Everglades and Biscayne National Parks, Miami-Dade County, and the mainland portion of Monroe County (BISCECT and habitat suitability models) as well as the urbanized coastal areas of Broward and Palm Beach counties to the north for the SLOSH and HAZUS models (Fig. 2).

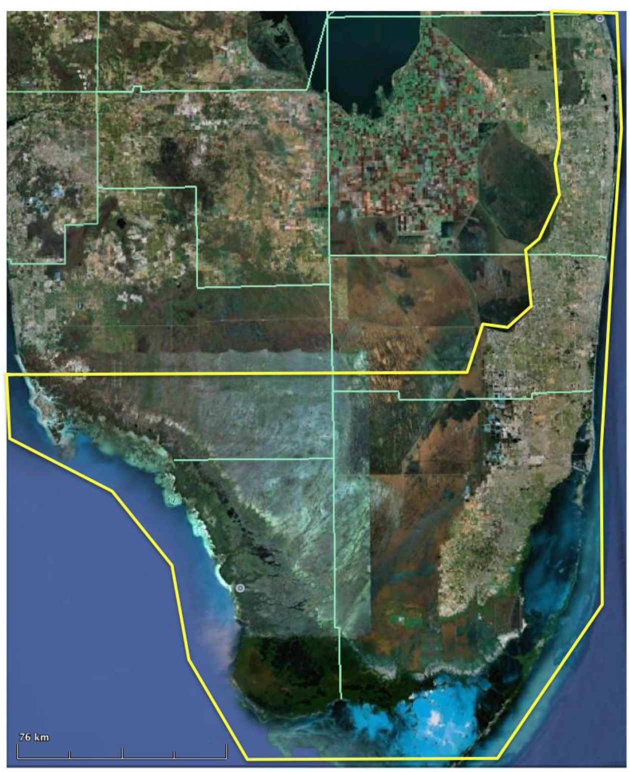

Figure 2 - IMMAGE study area (boundary indicated by yellow line)

Objectives

IMMAGE will develop a coupled GIS-enabled web-based decision support (DS) framework to provide interactive model-based scenarios to evaluate the potential impact of sea level rise on water supply, inland flooding, storm surge, and habitat management in South Florida. The DS framework will be developed to allow scientists, local planners and resource managers to evaluate the impact of sea level rise on:

1) salt water intrusion into coastal water well fields
2) optimal use of canals to impede the inland movement of saline groundwater
3) urban flooding
4) risk to populated areas and natural habitat from catastrophic storm surge
5) wetland inundation periods and depths
6) habitat suitability

Methodology

FTLOADDS simulator and BISECT model

The Flow and Transport in a Linked Overland/Aquifer Density-Dependent System (FTLOADDS) simulator has been developed over a number of years to be a tool for representing the hydrologic system by accounting for all relevant factors. It began with a surface water application to the coastal area along Florida Bay using the SWIFT2D two-dimensional flow and transport simulator (Swain and others, 2004; Swain, 2005). Groundwater flow was incorporated into this simulation by coupling SWIFT2D with the SEAWAT simulator of groundwater flow and transport (Langevin and others, 2005). This coupled scheme is called FTLOADDS. The model area was expanded to encompass the whole Everglades National Park (ENP) area and referred to as the Tides and Inflows in the Mangrove Everglades (TIME) model (Wang and others, 2007). This model has been used to represent hydrologic restoration scenarios for the Comprehensive Everglades Restoration Plan (CERP).

The FTLOADDS simulator was additionally applied to the Ten Thousand Islands area (Swain and Decker, 2009) and to the Biscayne Bay coast (Wolfert-Lohmann and others, 2008; Swain and others, 2009). The Biscayne Bay model was then combined with the TIME model to produce the BIscayne SouthEastern Coastal Transport (BISECT) model. The BISECT model incorporates some of the most important natural and urban areas in south Florida and is very useful in examining the effects of hydrologic factors. Applications include future forecasts with varying levels of sea level rise in conjunction with CERP restoration changes and hindcast simulation to represent historical and transient conditions (Fig. 3).

Experiments on various sea-level rise (SLR) scenarios have been performed with the BIscayne SouthEastern Coastal Transport Model (BISECT), which uses the FTLOADDS simulator for flow and transport in a coupled hydrodynamic surface-water/ground-water system. The existing conditions simulation was run for the seven-year period

1/1/1996 through 12/31/2002. BISECT is a combination of two model domains that were developed separately: the TIME domain west of L- 31N canal (Wang and others, 2007) and the Biscayne domain from L-31N to offshore Biscayne Bay (Swain and others, 2009). This combination allows the examination of the entire coastal region from Barron River in the northwest all the way to the C-9 canal outlet in the northeast.

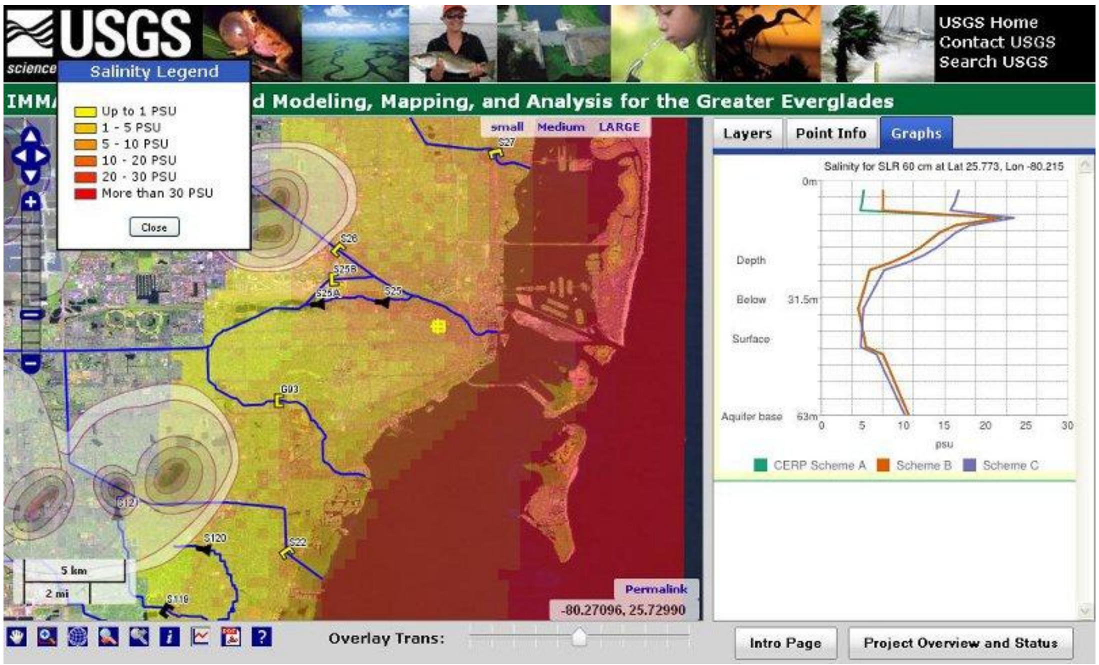

Figure 3 - This IMMAGE screenshot shows a BISECT analysis of the impact of a 60 cm (2 ft) sea level rise on the extent of salt water intrusion in the area around central Miami. Contours depict water well fields and groundwater travel times from various points; blue lines and black and yellow icons represent canals and surface water control structures. Forecasted groundwater salinities, depicted in the map view as the vertical average of salinities within the Biscayne Aquifer, indicate a clear threat to the two easternmost well fields. A more precise impact assessment is shown by the vertical profiles plotted by IMMAGE for the point indicated by the red cross, shown on the right side of the figure. These profiles reflect BISECT forecasts of salinity profiles for CERP Schemes A, B, and C. The model forecasts the CERP C (no action) scenario to result in increased groundwater salinities. The model predicts lower salinities for CERP A and B scenarios; however, the impact may still be sufficient to require mitigation.

Habitat and Species Dispersal Models

The coastal habitats of Everglades National Park are at the end of the hydrologic restoration chain, but are the first areas to be impacted by sea level rise. Both restoration and sea level rise may cause substantial spatial changes in habitat availability and location. Coastal models for juvenile spotted sea trout (*Cynoscion nebulosus*) habitat suitability (Ault and others, 2005) and amphibian species richness (Walls and others, 2010) have been developed at the South Florida Natural Resources Center, Everglades National Park (SFNRC/ENP) (Fig. 4). The models are coupled to the BISECT hydrologic model to simulate changes in habitat suitability under scenarios of restoration and sea level rise. In 2010, workshops with local species experts reviewed these models in a process of iterative improvement. The Java-based, modular structure of these models aids in making them readily web-enabled and interactive with the coupled framework of models in this proposal.

The ability of species to migrate among core habitat areas is impacted by changes in South Florida habitat connectivity resulting from urban growth, sea level rise and restoration-stimulated habitat succession. USGS, in cooperation with the SFNRC/ENP (Labiosa and others, 2009) is developing and testing metrics for ranking the potential for wildlife species dispersal under alternative changes to the natural landscape and urban growth. The Circuitscape model (McRae and others, 2008) provides the mechanism for evaluation of species dispersal. Circuitscape algorithms adapt electronic circuit theory to predict patterns of movement, gene flow, and genetic differentiation among plant and animal populations in heterogeneous landscapes.

The effort described in this work plan will provide additional support to the SFNRC/ENP habitat suitability assessment project by adapting the desktop user interface for deployment on the web.

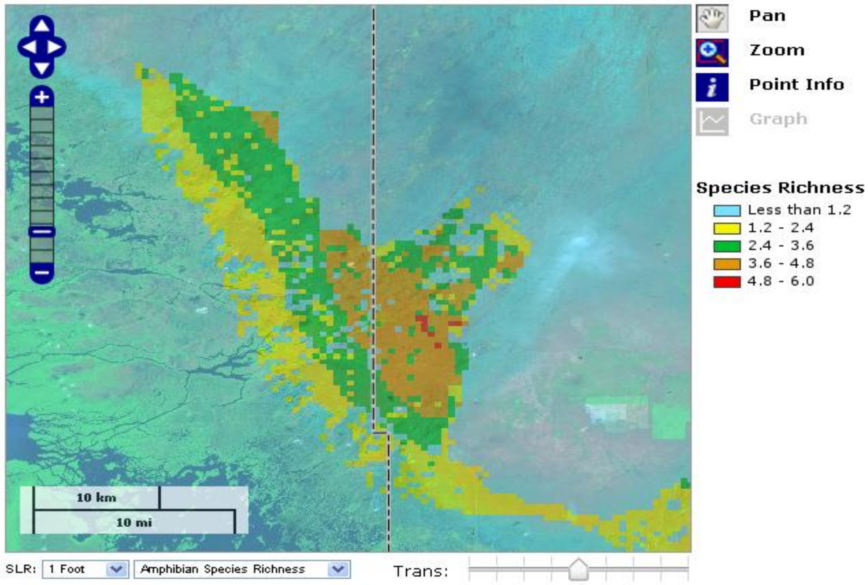

Figure 4 - Screenshot of the IMMAGE Habitat Suitability app showing forecasted amphibian species richness for a sea level rise of 1 foot

SLOSH Model

SLOSH (Sea, Lake and Overland Surges from Hurricanes) is a numerical model run by the National Hurricane Center (NHC) to estimate storm surge heights and winds resulting from historical, hypothetical, or predicted hurricanes (FEMA, 2003). SLOSH uses the hydrodynamic flow equations and requires input of bathymetry, coastal topography, surface characteristics, and tidal levels (Jelesnianski and others, 1992). The coastline is represented as a physical boundary. Sub-grid scale water features (cuts, chokes, sills and channels), and vertical obstructions (levees, roads, spoil banks, etc.) are parameterized. The SLOSH model does not include rainfall amounts, river flow, or wind-driven waves. These are combined with the model results in the final analysis of at-risk areas. SLOSH has been applied to the entire U.S. East Coast and Gulf of Mexico coastlines. In addition coverage extends to Hawaii, Guam, Puerto Rico, and the U.S. Virgin Islands.

Following up on the methodologies developed to incorporate the NOAA National Hurricane Center's SLOSH model into the HAZUS-MH Coastal Flood Model (CFM) by Longenecker (2008, 2009), FEMA Region IV developed a Coastal Flood Loss Atlas (CFLA) in an effort to improve risk assessments and mitigation planning for hurricane storm surges on the east coast of the United States. In order to establish a baseline "dictionary" to reference hurricane surge losses, this study uses SLOSH to establish maximum of maximum (MOM) potential storm surge depths by hurricane category in an effort to incorporate those estimates into HAZUS. SLOSH divides the coastline into basins and produces a water surface elevation grid used to determine depths by subtracting ground elevation. The SLOSH MOM grid is first converted to a raster surface elevation through centroid point interpolation, and then USGS 30-meter NED data is subtracted to determine depth over land.

HAZUS Surge Loss Analyses

Depth grids from the CLFA Surge MOM data were loaded into the HAZUS CFM to estimate Level 1 losses on a county-by-county basis, thereby establishing maximum losses per hurricane category class limits, on a broad basis.

For the IMMAGE project, SLOSH MOM inundation predictions and the accompanying HAZUS surge loss analyses were provided to USGS by FEMA Region IV for Miami-Dade, Broward, and Palm Beach counties. These data were then loaded into the IMMAGE map viewer (Figs. 5 and 6).

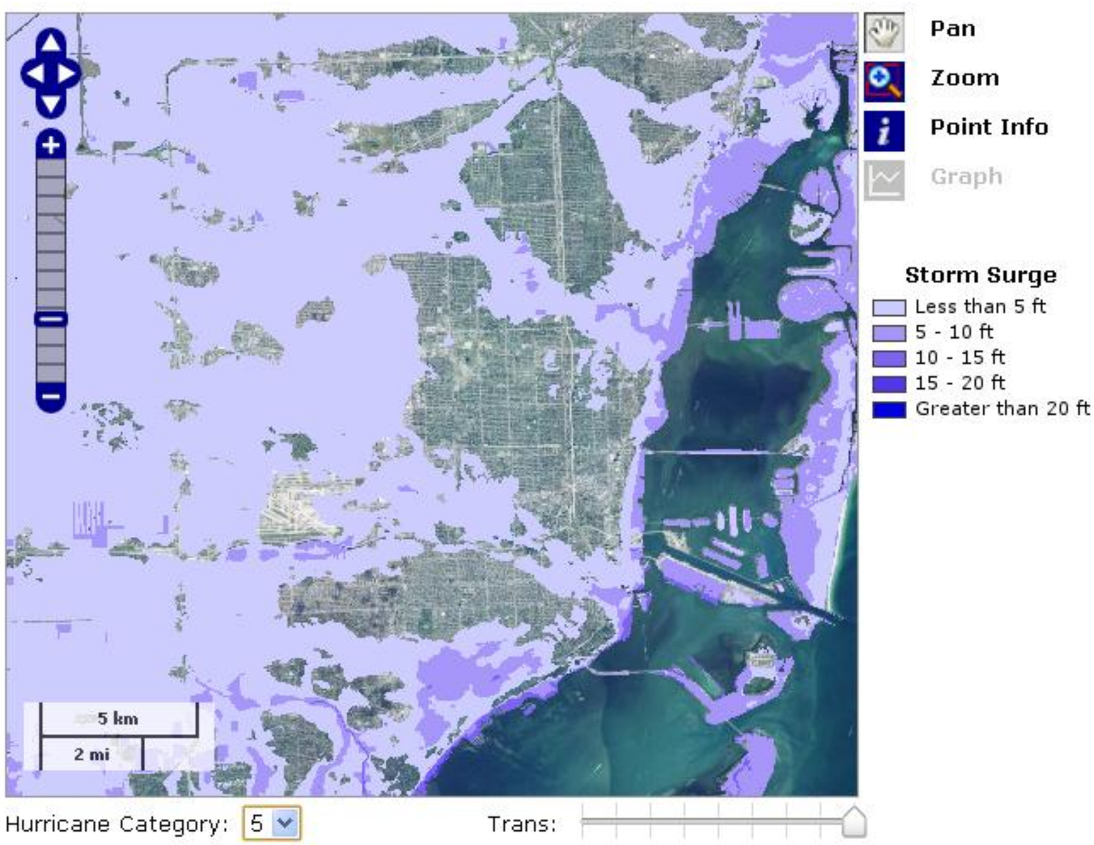

Figure 5 - Screenshot of the IMMAGE storm surge app, showing the spatial extent and depth of surge forecasted in the Miami area for a Category 5 hurricane

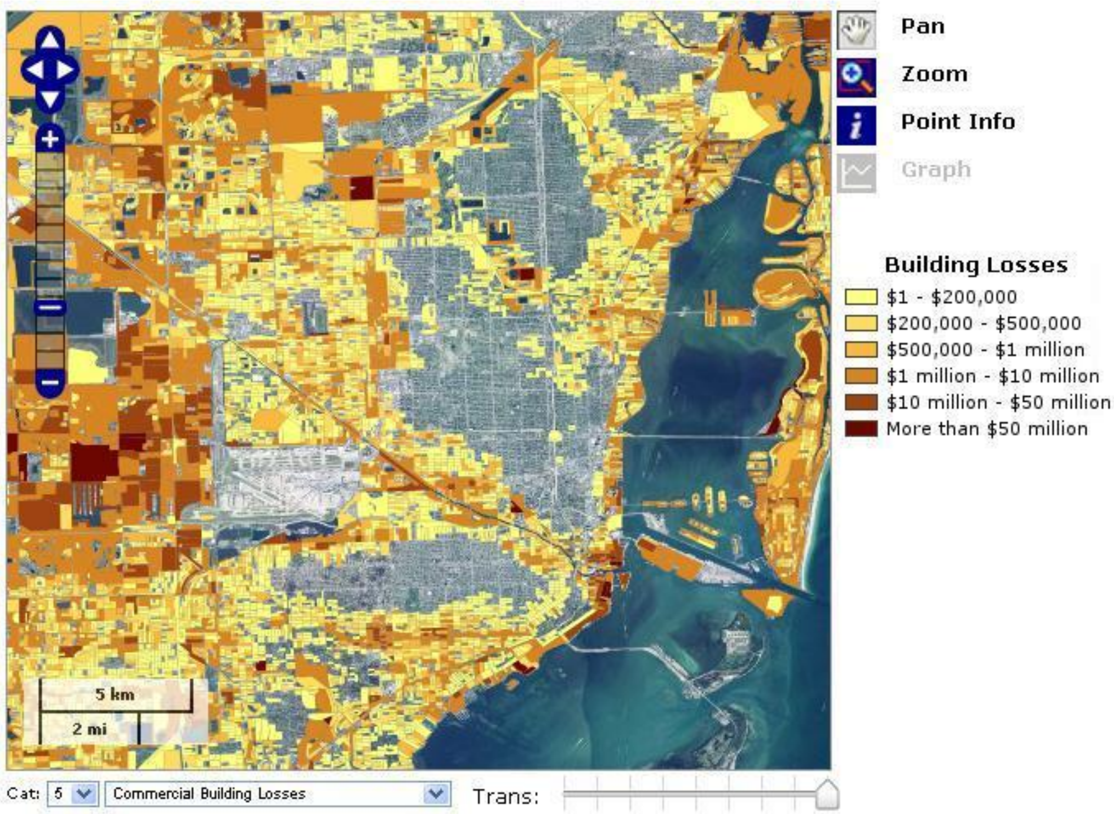

Figure 6 - Screenshot of the IMMAGE HAZUS Surge Loss app, showing the distribution of forecasted losses to commercial real estate in the Miami area for a Category 5 hurricane

IMMAGE Activities Under Consideration for FY 2013-2015

Developing an Improved Web-based Framework for the Management, Control, and Future Design of the Surface Water Control Network

The surface water control network in the southeast coast of Florida is the dominant hydrologic feature and regulates the flow of surface water and groundwater (Fig. 7). The network can be divided into primary, secondary, tertiary, and local drainage. Numerical models are currently under development to simulate flow through the surface water control network and the control structures that regulate the system. This will allow quantification of the interconnectivity and the drainage/water-level controlling capabilities of the control network.

A primary goal of the IMMAGE project in FY13 and beyond is to allow the display and analysis of this information in a visual format that can be interpreted and used for management decision making. The initial step in developing an interface to analyze the surface-water control network is to construct a database of network configuration parameters.

Control structures exist on the different canal systems, usually gated spillways, gated culverts, or pump stations on the primary system, with manual-gated culverts and berms on the secondary and tertiary system. The system connects on the secondary and tertiary level to areal drainage and runoff through pipes. At the present time, information on the control network is divided among various county and municipal agencies. These data are in critical need of consolidation and integration. The IMMAGE interface provides a convenient framework in which to do this. This would allow the information on the surface water control network to be integrated with model-computed results from IMMAGE's Web-based tools.

The proposed surface water network modeling tools could be used for determining the flood and salinity control capabilities of the system. The entire surface water network for southeastern Florida contains numerous canals, control structures and connections (Fig. 7). Modeling efforts are initially confined to smaller regions of interest, and these can be applied to the new set of IMMAGE tools.

A series of simulations utilizing different sea level and climatic conditions would produce a variety of spatial information to support the management, control, and future design of the surface water control network.

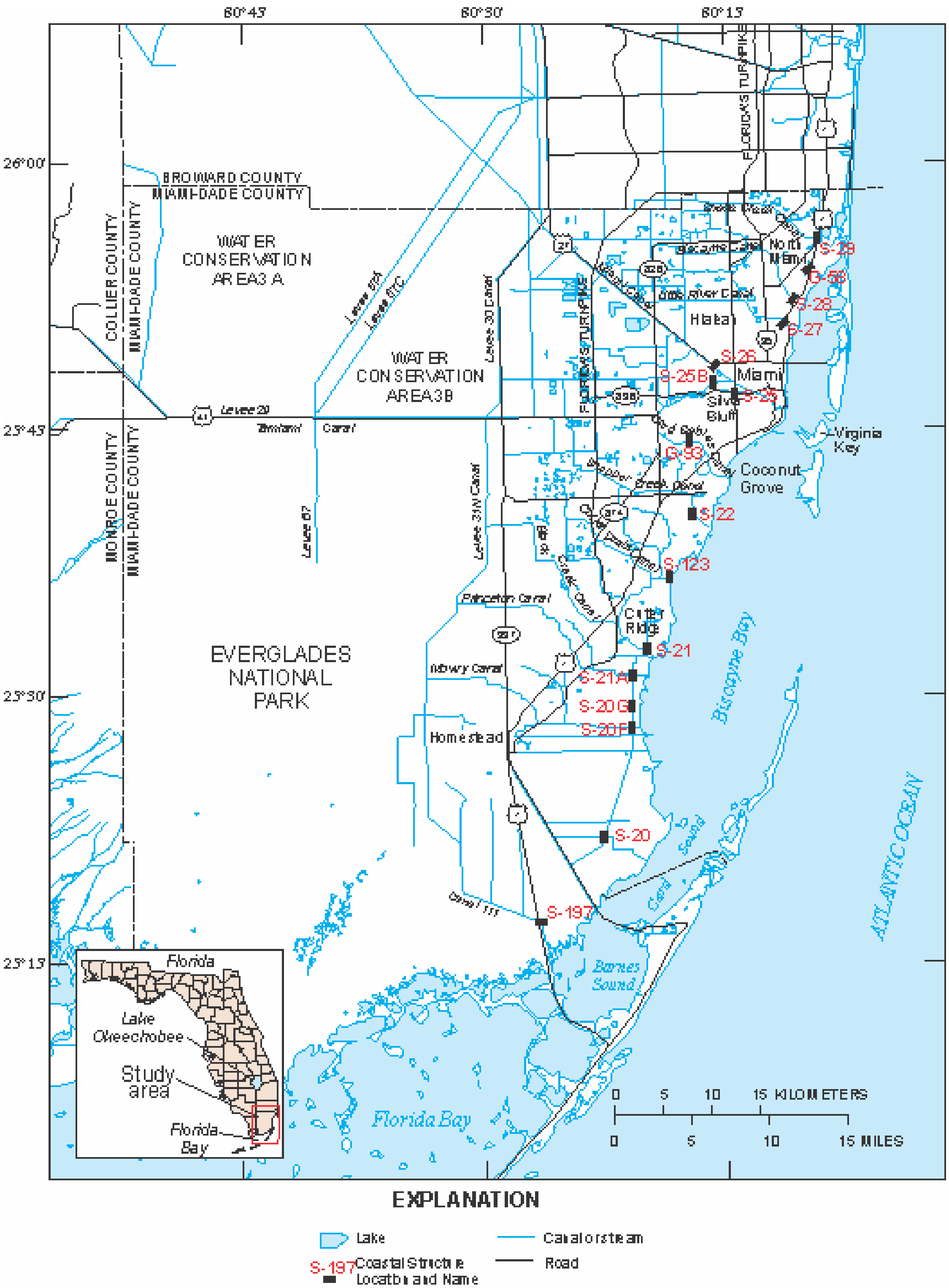

Figure 7 - Map of SE Florida's surface water control network

Applications of this spatial information could include:

1) Rating flood control capabilities by location and scenario (sea level rise, precipitation)

2) Defining canal control network optimization criteria and locations where flow connectivity places the most limitations on the ability of the system to maintain flood control (chokepoints)

3) User design of network connectivity by input of inundation criteria and control structure capacities

The numerical model computation could be also used to develop effective flow rating curves for the structures and canals in the control network. This information could then be used to develop a more interactive planning and design tool. Linear programming could be applied to this simplified scheme.

References

Ault, J.S., Smith, S.G., and Perry, W.B., 2005. Fishery Resource Habitat Use Modeling in Florida Bay: Development and Application to Everglades Restoration Implementation (Phase 1). NPS/CESU Technical Report, University of Miami, Miami, FL, 62 pp.

Deyle, R., Bailey, K., and Matheny, A., 2007. Adaptive Response Planning to Sea Level Rise Planning in Florida and Implications for Comprehensive and Public Facilities Planning. Department of Urban and Regional Planning, Florida State University, 49 pp.

FEMA, 2003a. "Multi-hazard loss estimation methodology, flood model, HAZUS, technical manual." Washington, D.C.

FEMA, 2003b. "HAZUS-MH User Manual." Washington, D.C.

Jelesnianski, C. P., Chen, J., and Shaffer, W. A., 1992. SLOSH: Sea, Lake, and Overland Surges from Hurricanes. NOAA Technical Report NWS 48, National Oceanic and Atmospheric Administration, U. S. Department of Commerce, 71 pp.

Labiosa, W.B., Bernknopf, R., Hearn, P., Hogan, D., Strong, D., Pearlstine, L., Mathie, A.M., Wein, A.M., Gillen, K., and Wachter, S., 2009. The South Florida ecosystem portfolio model—A map-based multicriteria ecological, economic, and community land-use planning tool: U.S. Geological Survey Scientific Investigations Report 2009-5181, 41 pp.

Langevin, C.D., Swain, E.D., and Wolfert, M.A., 2005. Simulation of integrated surface-water/ ground-water flow and salinity for a coastal wetland and adjacent estuary: Journal of Hydrology 314, 212-234.

Longenecker, H. E., 2008. "HAZUS Coastal Flood Module: FEMA Region IV Standard Operating Procedure for Coastal Flood Hazard & Loss Analysis." Internal FEMA Region IV document, available upon request from the Atlanta, GA office.

Longenecker, H. E., 2009. "An Evaluation of the HAZUS Coastal Flood Model." Master's Thesis, University of Colorado at Boulder.

McRae, B.H., Dickson, B.G., Keitt, T.H., and Shah, V.B., 2008. Using circuit theory to model connectivity in ecology and conservation. Ecology 10: 2712-2724.

Pearlstine, L., Hallac, D., Perry, W., Schmidt, T., Kearns, E., Bahm, K., and Swain, E., 2008. Florida Bay Estuarine Habitat Suitability Assessments of Restoration and Sea-level Rise Interactions, Greater Everglades Ecosystem Restoration Conference, Program and Abstracts, p. 362.

Pearlstine, L., DeAngelis, D., Mazotti, F., Barnes, T., Duever, M., and Starnes, J., 2006. Spatial Decision Support Systems for Landscape Ecological Evaluations in Southwest Florida Feasiibiity Study. CIR 1479, Wildlife Ecology and Conservation Department, University of Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, 6 pp.

Swain, E.D., Wolfert, M.A., Bales, J.D., and Goodwin, C.R., 2004. Two-dimensional hydrodynamic simulation of surface-water flow and transport to Florida Bay through the Southern Inland and Coastal Systems (SICS): USGS Water-Resources Investigations Report 03-4287, 56 pp. plus 6 plates.

Swain, E.D., 2005. A model for simulation of Surface-Water Integrated Flow and Transport in Two dimensions: SWIFT2D user's guide for application to coastal wetlands: U.S. Geological Survey Open-File Report 2005-1033, 88 pp.

Swain, E.D., and Decker, J.D., 2009. Development, Testing, and Application of a Coupled Hydrodynamic Surface-Water/Ground-Water Model (FTLOADDS) with Heat and Salinity Transport in the Ten-Thousand Islands/Picayune Strand Restoration Project Area, Florida: U.S. Geological Survey Scientific Investigations Report 2009-5146.

Swain, E.D., Lohmann, M., and Decker, J., 2009. Hydrological simulations of water-management scenarios in support of the Comprehensive Everglades Restoration Plan: In The Role of Hydrology in Water Resources Management (Proceedings of a symposium held on the island of Capri, Italy, October 2008). IAHS Publ. 327. pp. 296-305.

Walls, S., Pearlstine, L., Rice, K., Barichvich, J., Waddle, H., Romañach, S., and Duverney, D., 2010. Greater Everglades Amphibians Model Requirements Document. Joint Ecosystem Modeling. U.S. Geological Survey, Davie, FL, 16 pp.

Wang, J.D., Swain, E.D., Wolfert, M.A., Langevin, C.D., James, D.E., and Telis, P.A., 2007. Applications of Flow and Transport in a Linked Overland/Aquifer Density Dependent System (FTLOADDS) to simulate flow, salinity, and surface-water stage in the Southern Everglades, Florida. US Geological Survey Scientific Investigations Report 2007-5010.

Wolfert-Lohmann, M.A., Langevin, C.D., Jones, S.A., Reich, C.S., Wingard, G.L., Kuffner, I.B., and Cunningham, K.J., 2008. U.S. Geological Survey Science Support Strategy for Biscayne National Park and Surrounding Areas in Southeastern Florida: U.S. Geological Survey Open-File Report 2007-1288, 47 pp.